DOWNDRAFT GASIFICATION SYSTEM AND METHOD

Applicant: All Power Labs, Inc., Berkeley, CA (US)

Inventors: James Mason, Berkeley, CA (US); Nicholas Blindeutal, Berkeley, CA (US); Ryan Hasty, Berkeley, CA (US); Bear Kaufmann, Berkeley, CA (US); James Regulinski, Berkeley, CA (US); Austin Liu, Berkeley, CA (US)

Appl. No.: 14/593,701
Filed: Jan. 9, 2015

Related U.S. Application Data
Provisional application No. 61/925,635, filed on Jan. 9, 2014, provisional application No. 61/925,671, filed on Jan. 10, 2014.

Publication Classification
Int. Cl.
C10J 3/26 (2006.01)
C10J 3/32 (2006.01)
C10B 21/00 (2006.01)
C10J 3/00 (2006.01)

CPC
C10J 3/26 (2013.01); C10J 3/007 (2013.01);
C10J 3/32 (2013.01); C10B 21/00 (2013.01);
C10J 2200/158 (2013.01); C10J 2200/09 (2013.01)

ABSTRACT
A gasifier configured to receive biomass, including: a pyroreactor defining a first end, a second end, and an interior lumen, the first end defining a biomass inlet, the second end defining a pyroreactor outlet; a reduction basket arranged proximal the pyroreactor outlet, the reduction basket including a closed end and a basket opening opposing the closed end; a set of air manifolds fluidly connected to the interior lumen of the pyroreactor through a set of air inlets arranged between the first and second ends, proximal the second end; and a gasifier housing enclosing the pyroreactor, reduction basket, and set of air manifolds within a housing lumen.
DOWNDRAFT GASIFICATION SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Nos. 61/925,635 filed 9 Jan. 2014, and 61/925,671 filed 10 Jan. 2014, which are incorporated in its entirety by this reference.

TECHNICAL FIELD

[0002] This invention relates generally to the gasification field, and more specifically to a new and useful downdraft gasification system and method in the gasification field.

BRIEF DESCRIPTION OF THE FIGURES

[0003] FIG. 1 is a sectional view of a variation of the downdraft gasification system.
[0004] FIG. 2 is a schematic representation of a variation of the downdraft gasification system connected to a generator configured to convert gas produced by the gasifier to rotational energy and/or electrical power, including the biomass flow path through the gasifier, the char flow path through the gasifier, and the gas flow path through the gasifier.
[0005] FIG. 3 is a cutaway view of a variation of the solid removal mechanism fluidly connected to the gasifier.
[0006] FIG. 4 is an isometric view of the pyroreactor and air manifolds.
[0007] FIG. 5 is a cutaway view of a variation of the reduction container including a char director.
[0008] FIG. 6 is an isometric view of a variation of the agitation mechanism.
[0009] FIG. 7 is an isometric view of a variation of the solid removal mechanism.
[0010] FIG. 8 is a top-down view of a variation of the solid removal mechanism arranged within the gasifier and fluidly connected to an external char container.
[0011] FIG. 9 is a top-down view of a variation of the conveyor interfacing with a variation of the toothed perimeter.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] The following description of the preferred embodiments of the invention is not intended to limit the invention to these preferred embodiments, but rather to enable any person skilled in the art to make and use this invention.

[0013] As shown in FIG. 1, the downdraft gasification system (gasifier 100) includes a pyroreactor 200, a reduction container 300, a set of air manifolds 400, and a gasifier housing 500 enclosing the pyroreactor 200, reduction container 300, and set of air manifolds 400. The downdraft gasification system functions to convert biomass 10 into syngas 30 (synthesis gas or synthetic gas) or producer gas, which can subsequently be fed to a generator to convert the gas into mechanical or electrical energy. The system can additionally function to convert the biomass 10 into char 20, which can be removed from the gasifier 100 and used as terra preta or used in any other suitable manner.

[0014] The gasifier 100 is preferably a downdraft gasifier 100. In one variation, as shown in FIG. 2, the gasifier 100 can define a fixed bed drying zone 110, a fixed bed pyrolysis zone 120 fluidly connected to the drying zone 110, a fluidized bed combustion zone 130 fluidly connected to the drying zone 110, and a fluidized bed reduction zone 140 fluidly connected to the combustion zone 130. In one variation, the reduction bed is located beneath the combustion zone 130 along a gravity vector, the combustion zone 130 is located beneath the pyrolysis zone 120 along the gravity vector, and the pyrolysis zone 120 is located beneath the drying zone 110 along the gravity vector. However, the gasifier can be any other suitable gasifier, and the gasification zones can be defined and/or arranged in any other suitable manner.

[0015] In operation, as shown in FIG. 2, biomass 10 can be introduced through a biomass inlet 210 into the drying zone 110 in which the biomass 10 is dried. Flow along a gravity vector to the pyrolysis zone 120 in which the biomass 10 is pyrolyzed, along a gravity vector to the combustion zone 130 in which the biomass 10 is combusted, and along a gravity vector to the reduction zone 140 in which the biomass 10 is reduced to char 20 and gas 30. The combustion flow can be linear (e.g., downward, spinned (e.g., rotate about the longitudinal axis 211 of the combustion zone 130 and/or pyroreactor 200), or have any other suitable flow pattern. Combusted biomass transfer to the reduction zone 140 can additionally be facilitated by forced airflow through the air manifolds 400, vacuum generated by gas flow upward toward the gas manifold, and/or vacuum generated by generator consumption of the gas.

[0016] In the reduction zone 140, the gas 30 is preferably directed downward, toward the reduction container 300, then redirected by the reduction container 300 (e.g., by the closed ends of the container) toward the sides and open end 320 of the container. However, the gas 30 can flow in any other suitable direction. The gas 30 can flow upward against the gravity vector due to force from the combustion airflow, density gradients, and/or suction from the generator fluidly connected to the gasifier 100. The gas 30 preferably flows through a first fluid path defined between the pyroreactor 200 and a gasifier housing 500. The first fluid path is preferably tortuous, wherein the tortuous fluid path can be cooperatively defined by a set of air manifolds 400 extending from the gasifier housing 500 to the combustion zone 130, such that particulates entrained within the gas are filtered out by the tortuous flow. However, the first fluid path can include a set of baffles, be unobstructed, or have any other suitable configuration. The gas 30 then flows through a gas inlet 610 arranged above the reduction zone 140, more preferably above the combustion and/or pyrolysis zones, into a second gas manifold, wherein the secondary gas manifold is preferably fluidly connected to a filter and/or generator. However, the gas 30 can flow in any other suitable manner.

[0017] The char is preferably directed by the combustion flow toward the reduction container 300, wherein the reduction container 300 can transiently retain char particles above a threshold particle size within the container and/or maintain the char particle contact with the tar gas 30 produced by the combustion zone 130. This can facilitate longer resident time for tar gas cracking. The reduction container 300 can be agitated (e.g., mutated, translated in a periodic, repeating angular direction) to sift char particulates below the threshold size out the reduction container bottom (closed end 310) and side, while moving larger char particles toward the top of the container, proximal the combustion zone 130. The char can additionally fall out the top of the reduction container 300 when the reduction container volume is exceeded, such that excessive char buildup is prevented. The char can be caught by a char container arranged below the reduction container.
300 along a gravity vector, wherein the char container can be formed by a gasifier housing bottom 530, a separate container, the solid removal mechanism 700, or any other suitable component. The char can be removed from the gasifier interior by a solid removal mechanism 700, wherein a feeder mechanism 720 feeds the char toward a gasifier perimiter to a conveyor 710, wherein the conveyor 710 (e.g., screw conveyor) moves the char out of the gasifier 100 into an external char container. However, the char can flow in any other suitable manner.

[0018] The gasifier 100 can additionally utilize waste heat from different processes to heat other processes. In particular, in the drying zone 110, the biomass can be dried with waste heat from the pyrolysis zone 120. The biomass can be pyrolyzed in the pyrolysis zone 120 with waste heat from the combustion zone 130, the char 20 and gas 30 can be reduced with latent heat from the biomass combustion, and the air 40 provided to the combustion zone 130 for combustion can be heated with waste heat in the gas 30 after reduction. Heating the air 40 with the hot gas can additionally function to cool the gas, such that the gas 30 closer to a suitable temperature for gas filtration and/or generator use. The gas 30 can be further cooled in the secondary gas manifold in variations where a portion (e.g., a wall) of the secondary gas manifold is exposed to the ambient environment. However, the waste heat of the gasification zones can be otherwise utilized.

[0019] As shown in FIG. 1, the pyroreactor 200 of the gasifier 100 functions to define the pyrolysis zone 120 and combustion zone 130. The pyroreactor 200 can additionally define the drying zone 110. The pyroreactor 200 preferably includes a first end 250, a second end 260, and a body 240 extending between the first and second ends, wherein the body 240 can define a pyroreactor lumen 214 (interior lumen). The drying, pyrolysis, and/or combustion zones are preferably defined along adjacent portions of the body length within the pyroreactor lumen 214, but can alternatively be defined in any other suitable manner. The pyroreactor 200 can be partially located within the housing lumen 510 defined by the gasifier housing 500, entirely encapsulated within the housing lumen 510, or located in any other suitable position relative to the housing 500. The pyroreactor 200 is preferably arranged above the reduction container 300 along a gravity vector, but can alternatively be arranged in any other suitable position relative to the reduction container 300. The pyroreactor 200 can be connected to the gasifier housing 500, supported by an exterior support member, or retained in its position in any other suitable manner. The pyroreactor first end 250 can be connected to (e.g., mounted to) the first end of the gasifier housing 500, formed as a singular piece with the gasifier housing 500, or otherwise retained relative to the gasifier housing 500. The first end 250 of the pyroreactor 200 can be substantially open or closed. In one variation, the first end 250 includes a biomass inlet 210 configured to receive biomass in bulk. In a second variation, the first end 250 includes a biomass inlet 210 configured to receive biomass from a hopper or other biomass container, as shown in FIG. 3. The biomass inlet 210 can be substantially unobstructed, include an airlock (e.g., such as that disclosed in U.S. application Ser. No. 13/833,918, filed 15 Mar. 2013, incorporated herein in its entirety by this reference), or include any other suitable biomass metering device. The first end 250 can additionally or alternatively include an offgassing outlet that functions as an outlet for gasses driven off by the drying process (e.g., excess water or fumes). The offgassing outlet can be connected to an offgassing manifold that redirects the evaporate to the reduction zone 140 or any other suitable zone. However, the first end 250 can include any other suitable component, or have any other suitable configuration.

[0020] The second end 260 of the pyroreactor 200 can function to define the combustion zone interface with the reduction zone 140. The second end 260 preferably defines a pyroreactor outlet 220 through which the combustion products egress into the housing lumen 510, but can alternatively define a gaseous inlet or any other suitable feature. The second end 260 preferably opposes the first end 250 across the remainder of the body, but can alternatively be arranged in any other suitable position. The pyroreactor outlet 220 and the first end 250 are preferably substantially coaxial, but can alternatively be offset or otherwise configured. The normal vectors of the pyroreactor outlet 220 and the first end 250 are preferably parallel, but can be offset or otherwise configured. However, the first and second ends can be otherwise arranged.

[0021] The pyroreactor body 240 of the pyroreactor 200 functions to retain the biomass for pyrolysis, combustion, and/or drying. The pyroreactor body 240 can additionally function to fluidly couple the pyrolysis, combustion, and/or drying zones, thermally couple the pyrolysis, combustion, and/or drying zones, direct biomass flow, direct airflow (e.g., within the combustion zone 130), structurally support the air manifolds 400, or perform any other suitable functionality. The body preferably forms a tube and defines a pyrolysis lumen (interior lumen) that contains the pyrolysis, combustion, and/or drying zones. The body can have a circular or oval cross section (e.g., be a cylinder), rectangular cross section, or have any other suitable cross section. The body is preferably substantially straight, but can alternatively be curved or have any other suitable configuration. The body is preferably substantially unobstructed, but can alternatively include fins, baffles, or any other suitable interior feature. The interior features be arranged between the gasification zones, and can function to divide and/or regulate biomass flow between the gasification zones. Alternatively, the body be tapered along portions of the body length, wherein the interior wall of the body defines the interior feature. However, the body can have any other suitable construction.

[0022] In one variation, the pyroreactor body 240 defines a main body and a second body end, wherein the second body end is tapered toward the pyroreactor outlet 220, such that the pyroreactor outlet 220 has a smaller diameter than the main body. Alternatively or additionally, the second body end can taper toward the pyroreactor longitudinal axis 211, then flare outward toward the pyroreactor body 240 diameter toward the pyroreactor outlet 220, such that a throat (e.g., constricted flow area) is created between the air inputs and the pyroreactor outlet 220. Alternatively, the second body end can flare out from the remainder of the main body, such that the pyroreactor outlet 220 has a larger diameter than the main body diameter. However, the second body end can be otherwise configured. The second body end can be substantially smooth and linear, be curved, or have any other suitable configuration. The second body end is preferably tapered and forms an obtuse angle with the main body, but can alternatively form a right angle with the main body or acute angle with the main body. The angle can be between 180 and 90 degrees, between 150 and 120 degrees, be 135 degrees, or have any other suitable angle. Alternatively, the second body end can be substantially straight and parallel with the main body walls. However, the pyroreactor body 240 can have any other suit-
able configuration. The second body end interior is preferably substantially smooth, but can alternatively be grooved, include fins, or include any other suitable set of features.

[0023] The body can additionally define a set of air inlets 270 that function to fluidly connect the air manifolds 400 to the combustion zone 130. The air inlets 270 are preferably arranged along the main body, before the second body end distal the second end or pyroreactor outlet 220, but can alternatively be arranged along a portion of the second body end or arranged in any suitable position. The air inlets 270 are preferably arranged with the normal vectors aligned in a plane substantially parallel the pyroreactor outlet 220, but can alternatively be arranged in an array along the length of the pyroreactor body 240 (e.g., along the length of the second body end), an array spiraling about the pyroreactor body longitudinal axis 211, or arranged in any other suitable configuration. The body can include the same number of air inlets 270 as there are air manifolds 400, but can alternatively include more (e.g., wherein each air manifold 400 feeds into one or more air inlets 270) or less (e.g., wherein each air inlet 270 is fluidly connected to one or more air manifolds 400).

[0024] The set of air inlets 270 are preferably defined through the thickness of the pyroreactor body 240, but can alternatively be defined as manifolds extending along a portion of the body length (e.g., through the first end 250 or second end 260) or extend in any suitable configuration. The set of air inlets 270 can be defined perpendicularly to the wall through the wall thickness, at an angle to the wall thickness (e.g., at an angle between the wall tangent and the wall normal vector), or defined at any other suitable angle. The air inlet 270 can direct fluid (e.g., gas) radially inward toward the longitudinal axis 211 of the pyroreactor body 240, along a vector toward the second end 260, along a vector perpendicular to the pyroreactor outlet 220; along a non-perpendicular vector to the pyroreactor outlet 220, along a tangent to the pyroreactor internal wall; along a vector at a non-zero angle (e.g., perpendicular) to a tangent of the pyroreactor internal wall; or along any other suitable vector. In one variation, the air inlets 270 can cooperatively or individually induce rotational flow about the longitudinal axis 211 of the pyroreactor body 240. In a second variation, the air inlets 270 can create laminar or linear flow substantially parallel the longitudinal axis 211 of the pyroreactor body 240 (e.g., toward the second end 260). However, the air inlets 270 can have any other suitable configuration.

[0025] The pyroreactor 200 can additionally include a combustion mechanism 280 (burner) that functions to combust the pyrolyzed biomass. The combustion mechanism 280 can be arranged within the pyroreactor lumen 214, proximal the air inlets 270, but can alternatively be arranged at any other suitable position. The combustion mechanism 280 is preferably directed toward the second end 260, but can alternatively be directed in any other suitable direction.

[0026] The pyroreactor 200 can additionally include thermal insulation 290 that substantially thermally insulates all or a portion of the pyroreactor 200. The thermally insulation can extend along the main body, the second body end, or along any other suitable portion of the pyroreactor 200. The thermal insulation 290 can include insulation foam, vacuum insulation, or any other suitable thermal insulation 290. Alternatively, the pyroreactor 200 can be thermally conductive.

[0027] The reduction container 300 (reduction basket) of the gasifier 100 functions to define an elevated reduction bed. The reduction container 300 can function to transiently retain char produced by biomass combustion (e.g., increase tar gas 30 and/or char residence time to increase reduction efficiency), redirect gas flow from the pyroreactor 200 to form a fluidized reduction bed, and/or actively control char rise height. In one variation, the reduction container 300 has a predefined height and is arranged a predetermined distance away from the pyroreactor 200, such that a gap (spillway) is defined between the reduction container walls 330 and the pyroreactor body 240. This gap enables the char that rises above the reduction container height to spill out of the reduction container 300, such that the char does not build up and rise into the first gas manifold section. By predefining the height of the reduction bed, the reduction container 300 can additionally prevent char accumulation and/or packing.

[0028] The reduction container 300 preferably includes a closed end 310 and a set of walls 330 cooperatively defining an open end 320 opposing the closed end 310. The closed end 310 and/or walls can be perforated, such that char particulates under a threshold size (the perforation size) can express the reduction container 300 through the perforations. The perforations are preferably an array of circular apertures, but can alternatively be linear apertures or have any other suitable configuration. However, the closed end 310 and/or walls can be substantially solid, include fins or grooves, or have any other suitable feature. The reduction container cross section can be circular, rectangular, polygonal, or have any other suitable shape. The walls preferably flare outward from the closed end 310 (e.g., join to the closed end 310 at an obtuse angle), but can alternatively taper inward from the closed end 310 (e.g., join to the closed end 310 at an acute angle), join perpendicularly to the closed end 310, or be configured in any other suitable manner. The open end 320 is preferably cooperatively defined by the edge of the walls distal the closed end 310, but can alternatively be defined in any other suitable manner. The diameter or other dimension of the open end 320 is preferably larger than a diameter or dimension of the pyroreactor outlet 220, more preferably larger than a diameter or dimension of the pyroreactor body 240, but can alternatively be substantially equal or smaller. The reduction container 300 is preferably arranged with the open end 320 proximal the pyroreactor outlet 220 and the closed end 310 distal the pyroreactor outlet 220, but can alternatively be arranged in any other suitable configuration. The reduction container 300 is preferably arranged with the normal vector of the closed end 310 and/or open end 320 substantially parallel the normal vector of the pyroreactor outlet 220, but can alternatively be arranged in any other suitable configuration. The reduction container 300 is preferably arranged with the open end 320 a predetermined distance away from the pyroreactor outlet 220, but can alternatively be coplanar with the pyroreactor outlet 220, be arranged such that the pyroreactor outlet 220 is encompassed by a volume defined by the reduction container 300, or be arranged in any other suitable configuration. The reduction container 300 can be coaxially arranged with the pyroreactor 200, or be arranged offset from the pyroreactor 200.

[0029] As shown in FIG. 5, the reduction container 300 can additionally include a char director 350 that functions to direct char particulate flow toward the reduction container 300 closed end 310 and/or sides. The char director 350 is preferably coaxially arranged with the reduction container 300, but can alternatively be offset from the reduction container central axis 340. The char director 350 is preferably substantially coaxially aligned with the pyroreactor outlet
220, but can alternatively be offset from the pyroreactor outlet 220 or otherwise arranged. The char director 350 can be a cone, and can include an apex and a base 730, wherein the cone is preferably arranged with the apex proximal to the open end 320 of the reduction container 300 and the base 730 proximal or mounted to the closed end 310 of the reduction container 300. However, the cone can be otherwise arranged. The cone is preferably a right circular cone or frustrum of a right circular cone, but can alternatively have any other suitable configuration. The cone can be substantially solid or hollow. However, the char director 350 can be any other suitable mechanism capable of directing the flow of char. The char director surface can be perforated in a similar manner as the closed end 310 and/or walls 330, or can be substantially solid. The char director surface can be smooth, or additionally or alternatively include grooves, guides, or any other suitable feature that facilitates char transfer toward the closed end 310 and/or walls of the reduction container 300 (e.g., away from the pyroreactor 200). However, the char director 350 can have any other suitable configuration.

[0030] The reduction container 300 can additionally include an agitation mechanism 360 that functions to agitate the reduction container 300. The agitation mechanism 360 can function to prevent char packing within the reduction container 300. The agitation mechanism 360 can also function to filter finer char particles toward the closed end 310 of the reduction chamber, control the fine char egress rate through the perforations, and/or promote larger char particle rise toward the open end 320 of the reduction chamber. The agitation mechanism 360 can function to place the large char particles within the tar gas stream, which can increase the residence time of the tar gas 30 with the large char particles.

[0030] The agitation mechanism 360 preferably reciprocates the reduction container 300 in an arcuate or angular direction about an agitation or rotational axis (e.g., the central axis of the reduction container 300, extending substantially parallel a normal vector of the closed or open ends), but can alternatively reciprocate the reduction container 300 in a direction substantially parallel the central axis, reciprocate the reduction container 300 laterally (e.g., along a radius extending radially outward along a normal vector to the central axis), or in any other suitable direction. The reduction chamber can be angularly displaced approximately 10° between the extreme positions, but can alternatively be angularly displaced approximately 10° from a reference position at each extreme position, displaced more than 10° (e.g., 180°, 45°, etc.), rotated one or more full rotations, or angularly agitated in any other suitable manner. The agitation frequency (reciprocation frequency) can be predetermined, dynamically determined (e.g., based on packing measurements, gas flow, char mass flow, etc.), automatically determined (e.g., based on desired char flow, gas flow, gas quality, char quality, etc.), empirically determined (e.g., based on reduction container balance, wherein the system can additionally include a switch that temporarily ceases reciprocation in response to the reduction container 300 becoming unbalanced), or determined in any other suitable manner. The agitation acceleration can additionally be predetermined, dynamically determined, empirically determined, or determined in any other suitable manner. The agitation mechanism 360 can include a side rotary drive with a linear reciprocator (e.g., a three point star linear reciprocator, as shown in FIG. 6), an electric motor, or any other suitable agitation mechanism 360. The agitation mechanism 360 can be arranged below the reduction container 300 along a gravity vector, outside of the gasifier housing 500, or arranged in any other suitable position.

[0032] The set of air manifolds 400 of the gasifier 100 functions to fluidly connect the gasifier exterior to the combustion zone 130 within the pyroreactor 200 and transport air 40 from an oxygen source (e.g., the ambient environment, oxygen tank, etc.) to the combustion zone 130. The set of air manifolds 400 is preferably arranged within the housing lumen 510 (housing interior), more preferably within a gap defined between the gasifier housing interior and the pyroreactor exterior, as shown in FIG. 1. The air manifolds 400 can physically contact the pyroreactor 200, physically contact the housing interior, be offset from the pyroreactor 200, be offset from the housing interior, or be otherwise arranged relative to the pyroreactor 200 and/or housing 500. However, the air manifolds 400 can extend through the gas manifold, through the pyroreactor interior 212, or along any other suitable portion of the gasifier 100. The air manifolds 400 can have diameters slightly less than the gap defined between the pyroreactor 200 exterior and gasifier housing interior, diameters equal to the gap, or any other suitable dimensions. The air manifold 400 diameters are preferably substantially constant along the length of the air manifold 400, but can alternately vary. The diameters of different air manifolds 400 can be substantially the same or be different.

[0033] The air manifolds 400 preferably extend from a first end of the gasifier 100 (e.g., proximal the first end 250 of the pyroreactor 200) to the air inlets 270, but can alternatively extend from a second end of the gasifier 100 to the air inlets 270, extend radially inward from the gasifier wall to the air inlets 270, or extend from any other suitable portion of the gasifier 100. The air manifolds 400 preferably extend along the drying and pyrolysis zones, but can alternatively or additionally extend along all or a portion of the combustion zone 130 or any other suitable zone. The air manifolds 400 preferably wind about the pyroreactor 200 in a helical pattern, as shown in FIG. 4, but can alternatively extend substantially parallel to the pyroreactor 200 or perpendicular to the pyroreactor 200. The air manifolds 400 are preferably serpentine, wherein the closed loop of the air manifold 400 perimeter is rotated about the longitudinal axis 211 of the pyroreactor 200 (e.g., wherein a central axis of the air manifold 400 traces a helix about the longitudinal axis 211 of the pyroreactor 200), but can alternatively be substantially linear or have any other suitable configuration.

[0034] The housing 500 of the gasifier 100 functions to contain the gasifier components and biomass. The housing 500 can additionally function to mechanically protect the gasifier components, retain the gasifier component positions, and/or perform any other suitable functionality. The housing 500 preferably includes an inner wall that defines a housing lumen 510 encapsulating the pyroreactor 200, reduction basket, and set of air manifolds 400. The housing lumen 510 can function as the first gas manifold 540 that receives the reduced gas. The housing interior can additionally or alternatively include baffles, fins, or other features that function to create turbulent or tortuous gas flow as the gas rises through the housing lumen 510. The housing 500 can additionally include a top 520 that functions to substantially fluidly seal the housing lumen 510, a bottom that functions to capture char output from the reduction container 300, or any other suitable component. In one variation, the housing top 520 can support the air manifold ends. In another variation, the housing bottom 530 can include an aperture for the drive shafts of solid
removal mechanism 700 and/or agitation mechanism 360. However, the housing 500 can have any other suitable configuration. The gasifier housing 500 can be thermally insulated (e.g., with insulating foam, polymer vacuum casing, etc.) or be uninsulated and substantially thermally coupled to the ambient environment.

[0035] The gasifier 100 can additionally include a second gas manifold 600 that functions to receive the gas from the housing lumen 510 and directs the gas to a filter or downstream process. The second gas manifold 600 can additionally function to cool the gas, particularly in variations wherein a wall or other second gas manifold component is exposed to the ambient environment. The second gas manifold 600 is preferably substantially fluidly isolated from the housing lumen 510 along a majority of the annular void length. But can alternatively be substantially fluidly connected to the housing lumen 510. The second gas manifold 600 is preferably fluidly connected to the first gas manifold 540 (the housing lumen 510) by one or more gas inlets 610, but can alternatively be otherwise fluidly connected to the first gas manifold 540. The gas inlet 610 is preferably arranged proximal the first end of the gasifier or pyroreactor 200, but can alternatively be defined at any other suitable location along the gasifier length. The gas inlet 610 is preferably defined through the housing wall proximal the first end of the gasifier 100, but can additionally or alternatively be defined through an end of the gasifier 100 or defined through any other suitable portion of the gasifier 100. The second gas manifold 600 can include baffles, grooves, or any other suitable feature that can additionally function to direct and/or filter the gas flowing therethrough.

[0036] In a first variation, the second gas manifold 600 can be cooperatively defined between an outer wall 560 that encircles the gasifier housing 500 (inner wall), wherein the second gas manifold 600 is an annular void defined therebetween. The gas inlet 610 fluidly connecting the annular void to the housing lumen 510 is preferably defined through the thickness of the inner wall, but can alternatively be defined as a gap between the inner wall and the housing top 520, or defined in any other suitable manner. In this variation, the outlet of the second gas manifold 600 can be defined along the opposing end of the gasifier 100 (e.g., second end of the gasifier 100, proximal the reduction container 300 or second pyroreactor end 230) or defined in any other suitable position.

[0037] In a second variation, the second gas manifold 600 can be defined by tubing fluidly connected to the housing lumen 510, wherein the tubing can wrap around the gasifier exterior, extend along the gasifier length, or be arranged in any other suitable configuration. However, the second gas manifold 600 can be defined in any other suitable manner.

[0038] The gasifier 100 can additionally include a char grinder that functions to reduce char particulates to a combustion size. The char grinder can be arranged within the pyroreactor 200, between the pyrolysis zone 120 and the combustion zone 130 (e.g., between the first end and the second body end, between the first end and the air inlets 270, etc.), but can alternatively be arranged in any other suitable position. The char grinder can include a first, static plate that functions as an abrasive surface and a second, actuating plate that functions to abrade char against the static plate. The actuating plate preferably includes perforations that capture char larger than the combustion size, but can alternatively include any other suitable feature. The first plate preferably includes aperture substantially the dimensions of the combustion size, but can alternatively include any other suitable features.

[0039] The gasifier 100 can additionally include a solid removal mechanism 700 that functions to remove char from the gasifier 100. The solid removal mechanism 700 is preferably used with the gasifier 100 described above, but can additionally or alternatively be used with any other suitable gasifier configuration. The solid removal mechanism 700 preferably removes char that has been removed from the reduction container 300, but can additionally or alternatively remove any other suitable char from the gasifier 100. The solid removal mechanism 700 preferably removes char from the bottom (e.g., second end) of the gasifier 100, but can alternatively remove char from any other suitable portion of the gasifier. In one variation, the solid removal mechanism 700 includes a conveyor 710 coupled to a feeder mechanism 720. The solid removal mechanism 700 can be arranged with the feeder mechanism 720 arranged below the reduction container 300 along a gravity vector (e.g., opposing the pyroreactor 200 across the reduction container 300, as shown in FIG. 5), wherein the feeder mechanism 720 can be arranged coaxially with the reduction container 300 (e.g., with the rotational axis substantially coaxial with the reduction container 300 central axis), offset from the reduction container 300, offset from the pyroreactor 200, coaxially with the pyroreactor 200, or arranged in any other suitable configuration. The conveyor 710 can be arranged outside an imaginary volume defined by an extension of the pyroreactor 200 toward the feeder mechanism 720 (e.g., as shown in FIG. 8), arranged outside the gasifier diameter (e.g., outside the housing lumen 510), or arranged in any other suitable position. Alternatively, the conveyor 710 can be arranged below the reduction container 300 or pyroreactor 200 along the gravity vector (e.g., within the housing lumen 510), or be arranged in any other suitable position. However, the solid removal mechanism 700 can be otherwise arranged.

[0040] The conveyor 710 of the solid removal mechanism 700 functions to transport char out of the gasifier, and can additionally function to concurrently drive feeder mechanism rotation. The conveyor 710 can include a screw conveyor (auger) including a helical screw blade 712 configured to rotate about a rotational axis, wherein material is transported along the rotational axis. Alternatively, the conveyor 710 can include a conveyor belt, a set of buckets, or any other suitable material transport mechanism. The conveyor 710 is preferably fluidly connected to the feeder mechanism 720 at a point or along a portion of the conveyor length, such that the conveyor 710 receives solids (e.g., char) fed to the conveyor 710 by the feeder mechanism 720. The conveyor 710 can be connected at an opposing end or portion of the conveyor 710 to a solid takeoff (e.g., chute), solids container (e.g., a bin), or any other suitable solids receptacle. The conveyor 710 is preferably arranged at an elevated angle (e.g., with the second or opposing end above the first or feeder mechanism end, relative to a gravity vector), such that the conveyor 710 simultaneously removes solids from the gasifier system and elevates the removed solids. However, the conveyor 710 can be arranged substantially perpendicular to the gravity vector, be arranged at a decline, or be arranged in any suitable orientation. The conveyor 710 is preferably linear (e.g., the central axis is preferably linear), but can alternatively be curved or have any other suitable configuration.
[0041] The feeder mechanism 720 functions to drive (e.g., sweep) material from the gasifier interior toward the conveyor 710. As shown in FIGS. 7, 8, and 9, the feeder mechanism 720 can include a toothed perimeter 722 arranged in a first plane and a set of feeder blades 724 arranged in a second plane substantially parallel to the first plane. Alternatively, the toothed perimeter 722 and feeder blades 724 can be arranged in the same plane, intersecting planes, or any other suitable set of planes. The feeder mechanism 720 is preferably rotationally symmetric about the rotational axis, but can alternatively be rotationally asymmetric or have any other suitable configuration.

[0042] The toothed perimeter 722 of the feeder mechanism 720 functions to engage with the screw conveyor and rotate about a rotational axis, wherein screw conveyor rotation drives toothed perimeter 722 rotation. The toothed perimeter 722 can couple to the top, side, or any other suitable portion of the screw conveyor. The screw conveyor can be arranged with the screw conveyor rotational axis substantially parallel to the plane of the toothed perimeter 722, at an angle to the toothed perimeter plane, aligned with the toothed perimeter plane, or at any other suitable orientation relative to the toothed perimeter plane. The toothed perimeter 722 preferably includes a set of crenellations (e.g., teeth) along the external perimeter that function to transiently engage with the helical protrusions of the screw conveyor. The teeth can be arranged in the first plane, arranged at an angle to the first plane, or be arranged at any other suitable angle relative to the first plane. The toothed perimeter 722 is preferably a plate including a set of apertures therebetween, such that charcoal falls through the apertures to the feeder blades 724 (e.g., wherein the feeder blades are arranged beneath the toothed perimeter 722 along a gravity vector). However, the toothed perimeter 722 can be substantially solid (e.g., wherein the feeder blades 724 are above the toothed perimeter 722 along a gravity vector) or have any other suitable configuration.

[0043] The set of feeder blades 724 of the feeder mechanism 720 function to guide the material toward the perimeter of the feeder mechanism 720, wherein the conveyor 710 is arranged proximal to the feeder mechanism 720 perimeter. The set of feeder blades 724 are preferably statically connected to the toothed perimeter 722 (e.g., along the rotational axis, along the perimeter, etc.), wherein the feeder blades 724 rotate as the toothed perimeter 722 is rotated by the screw conveyor. However, the feeder blades 724 can be otherwise connected to the toothed perimeter 722. The feeder blades 724 are preferably arranged in a second plane offset from the first plane, but can alternatively be arranged in the first plane or any other suitable configuration. The feeder blades 724 can be substantially flat (e.g., lie within the second plane), angled (e.g., be arranged at an angle to the second plane), or be arranged in any other suitable orientation. In one variation, the feeder blades 724 are angled with the leading edge above the trailing edge (e.g., proximal the reduction container 300 relative to the trailing edge). In a second variation, the feeder blades 724 are angled with the leading edge below the trailing edge (e.g., distal the reduction container 300 relative to the trailing edge). The feeder blades 724 can be substantially straight, curved (e.g., having a 45° curvature, 30° curvature, etc.), or have any other suitable configuration. The feeder blade length can substantially match the gasifier diameter, can be slightly shorter than the gasifier diameter (e.g., wherein the solid removal mechanism 700 and/or feeder mechanism 720 fits within the gasifier 100), longer than the gasifier diameter (e.g., wherein the solid removal mechanism 700 is arranged below or outside of the gasifier 100), or have any other suitable configuration. The feeder mechanism 720 preferably includes a plurality of blades, but can alternatively include a single blade, two blades, or any suitable number of blades. The feeder blades 724 are preferably substantially evenly distributed about the rotational axis, but can alternatively be unevenly distributed (e.g., have different angular distances between a first and second set of adjacent feeder blades 724) or have any other suitable distribution.

[0044] The feeder mechanism 720 can additionally include a base 730 that functions to capture the char that egressed out of the reduction container 300. The base 730 is preferably arranged below the feeder blades 724 along a gravity vector, but can alternatively be arranged in any other suitable position. The base 730 preferably spans the entirety of the feeder blade length, but can additionally or alternatively be longer (e.g., wherein the base 730 can interface with the conveyor 710) or shorter. The base 730 can be statically coupled to the feeder blades 724 and/or toothed perimeter 722, such that the base 730 rotates with the feeder mechanism 720, or can be rotatably coupled such that the feeder blades 724 and/or toothed perimeter 722 rotate relative to the base 730 and/or the base 730 remains static relative to the gasifier. The base 730 can be pitched (e.g., angled or slanted) toward the perimeter, wherein the base 730 center is higher than the base perimeter. In this variation, the blades are preferably angled at the same angle of the base pitch relative to the axis of rotation, such that the blades substantially contact or include a face substantially parallel to the base surface. However, the blades can be at an angle to the base surface or have any other suitable configuration. Alternatively, the base 730 can be substantially flat, curved, or have any other suitable configuration. The base surface can be substantially smooth, grooved, or have any other suitable feature. However, the base 730 can have any other suitable configuration.

[0045] The solid removal mechanism 700 can additionally include a drive mechanism 740 that functions to drive solid removal mechanism actuation. In one variation, the drive mechanism 740 can drive the conveyor 710, wherein the conveyor 710 (e.g., the helical screw blade 712) engages with the toothed perimeter 722 of the feeder mechanism 720 and drives feeder mechanism rotation as the conveyor 710 is rotated. In this variation, the conveyor 710 is preferably rotated toward the feeder mechanism 720, but can alternatively be rotated away from the feeder mechanism 720. In a second variation, the drive mechanism 740 can drive the feeder mechanism 720, wherein the toothed perimeter 722 of the feeder mechanism 720 engages with the conveyor 710 (e.g., the helical screw blade 712) and drives conveyor 710 rotation as the feeder mechanism 720 is rotated.

[0046] The drive mechanism 740 can be an electric motor, a gearset driven by the generator, or be any other suitable drive mechanism 740 capable of applying a rotational force. The frequency of drive mechanism 740 rotation can be constant, dynamically adjustable (e.g., based on a desired solid material feed rate, the solid material generation rate, the solids volume in the gasifier 100, etc.), or otherwise determined. In one variation, the system can detect an obstruction in the feeder mechanism 720, conveyor 710, or interface between the feeder mechanism 720 and conveyor 710, drive the drive mechanism 740 in reverse to disengage the obstruction, and drive the drive mechanism 740 forward to continue solids removal from the gasifier 100. The obstruction can be
detected based on an increase in motor resistance, discrepancy in the expected and actual material flow rate, rapid flow rate change, or detected in any other suitable manner. Driving the mechanism in reverse can include driving the mechanism in reverse with the drive mechanism 740 or with a second drive mechanism 740. The mechanism can be driven in reverse for part of a rotation, a full rotation, multiple rotations, or any suitable number or portion of rotations.

Although omitted for conciseness, the preferred embodiments include every combination and permutation of the various system components and the various method processes.

As a person skilled in the art will recognize from the previous detailed description and from the figures and claims, modifications and changes can be made to the preferred embodiments of the invention without departing from the scope of this invention defined in the following claims.

We claim:
1. A gasifier configured to receive biomass, comprising:
   a pyroreactor defining a first end, a second end, and an interior lumen, the first end defining a biomass inlet, the second end defining a pyroreactor outlet;
   a reduction basket arranged proximal the pyroreactor outlet, the reduction basket comprising a closed end and a basket opening opposing the closed end;
   a set of air manifolds fluidly connected to the interior lumen of the pyroreactor through a set of air inlets arranged between the first and second ends, proximal the second end; and
   a gasifier housing enclosing the pyroreactor, reduction basket, and set of air manifolds within a housing lumen.

2. The gasifier of claim 1, wherein the air manifolds are fluidly connected to a gasifier housing exterior.

3. The gasifier of claim 1, wherein the pyroreactor is thermally insulated.

4. The gasifier of claim 1, wherein the pyroreactor further comprises a burner arranged within the interior lumen proximal the air inlets.

5. The gasifier of claim 1, wherein the second end is tapered toward the pyroreactor opening.

6. The gasifier of claim 1, wherein the reduction basket is arranged with the basket opening proximal the pyroreactor outlet.

7. The gasifier of claim 6, wherein the reduction basket closed end is perforated.

8. The gasifier of claim 6, wherein the reduction basket further comprises a set of perforated walls extending between the closed end and the opening.

9. The gasifier of claim 6, wherein the reduction basket further comprises an agitation mechanism.

10. The gasifier of claim 9, wherein the agitation mechanism is configured to angularly agitate the reduction basket about an agitation axis extending substantially normal to the closed end.

11. The gasifier of claim 6, wherein the reduction basket comprises a cone comprising an apex arranged proximal the basket opening and a base proximal the closed end.

12. The gasifier of claim 11, wherein the cone comprises a substantially smooth exterior.

13. The gasifier of claim 1, wherein the air inlets are directed toward the second end of the pyroreactor.

14. The gasifier of claim 13, wherein the air inlets are arranged in a non-perpendicular angle relative to a plane defined by the pyroreactor opening, such that the air inlets induce rotational flow.

15. The gasifier of claim 1, wherein the air manifolds are arranged between a pyroreactor exterior and a gasifier housing interior.

16. The gasifier of claim 15, wherein an air manifold diameter is slightly less than a gap defined between the pyroreactor exterior and gasifier housing interior.

17. The gasifier of claim 1, wherein the gasifier housing comprises an inner and outer wall cooperatively defining an annular void therebetween, wherein the inner wall comprises a gas inlet fluidly connected to the housing lumen.

18. A gasification system comprising: a solid removal mechanism comprising:
   a screw conveyor comprising a helical screw blade configured to rotate about a rotational axis;
   a feeder mechanism, comprising:
     a toothed perimeter configured to engage with the helical screw blade and rotate about a rotational axis, wherein helical screw blade rotation drives toothed perimeter rotation;
     a set of feeder blades statically coupled to the toothed perimeter, the set of feeder blades arranged in a plane offset from a plane defined by the toothed perimeter; and
   a drive mechanism coupled to the screw conveyor and configured to rotate the helical screw blade toward the feeder mechanism.

19. The gasifier of claim 18, wherein the screw conveyor rotational axis is arranged at a non-zero angle relative to the plane defined by the toothed perimeter.

20. The gasifier of claim 18, wherein the gasification system further comprises:
   a pyroreactor defining a first end, a second end, and an interior lumen, the first end defining a biomass inlet, the second end defining a pyroreactor outlet;
   a reduction container arranged proximal the pyroreactor outlet, the reduction basket comprising a closed end and a basket opening opposing the closed end;
   a set of air manifolds fluidly connected to the interior lumen of the pyroreactor through a set of air inlets arranged between the first and second ends, proximal the second end; and
   a gasifier housing enclosing the pyroreactor, reduction basket, and set of air manifolds within a housing lumen, the gasifier housing comprising a set of walls and a bottom, wherein the feeder mechanism is arranged between the reduction container and the gasifier bottom, and the screw conveyor is arranged outside an imaginary volume defined by an extension of the pyroreactor toward the feeder mechanism.

* * * * *